CLAIMS

What is claimed is:

1. An orthogonal frequency division multiplexing (OFDM) communication device, comprising:

an OFDM receiver for receiving an OFDM signal containing a multitone synchronization signal;

a synchronization interval sampler coupled to said receiver;

an initial time and frequency offset estimator connected to said sampler and said receiver; and

a frequency offset estimate refinement unit connected to said receiver, said sampler and said estimator, wherein a reference multitone synchronization signal is used by said estimator and said refinement device in calculating a time offset and a frequency offset of said multitone synchronization signal, said receiver utilizing said time offset and said frequency offset to synchronize with said received OFDM signal.

2. The system of claim 1, wherein said initial time and frequency offset estimator comprises:

a plurality of smoothed time-domain correlation estimators for outputting a series of time offset estimate and correlation estimate pairs, each pair related to a frequency offset estimate; and

a selector for selecting a selected time offset estimate and a selected initial frequency offset based in part upon the selection of the frequency offset estimate and time offset estimate that corresponds with the largest value of correlation estimate.

The system of claim 2, wherein each of said smoothed time domain correlation estimators comprises:

a time domain correlator;

a smoothing filter connected to said time domain correlator and receiving an output from said time domain correlator; and

a maximum detector connected to and receiving an output from said smoothing filter for detecting a signal energy maxima representing a time estimate at which the energy of said reference multitone synchronization signal is at a maximum.

3. The system of claim 2, wherein the initial time and frequency offset estimator uses a coarse frequency discretization using F candidate frequency offsets.

4. The system of claim 2, wherein said reference multitone synchronization signal has a length of T, and wherein said frequency offset estimate refinement device comprises:

a T-length interval extractor for extracting a T-length sample of the output of said sampler;

a numerical oscillator for generating a complex exponential of a candidate frequency offset;

a multiplier for multiplying said T-length sample with said complex exponential to obtain a frequency shifted received signal;

a correlator for correlating said frequency shifted received signal with said reference multitone synchronization signal and producing a correlation output; and

a numerical optimizer for receiving said correlation output and outputting a new frequency offset candidate.

5. The system of claim 5, wherein said new frequency offset candidate and a time offset associated with said new frequency offset candidate are used by said receiver if said new frequency offset candidate is a candidate that yields a maximum correlation output.

6. The system of claim 1, wherein said initial time and frequency offset estimator comprises:

a first Fast Fourier Transformer for obtaining a transform of said received signal;

an second Fast Fourier Transformer device for obtaining a transform of said reference multitone synchronization signal;

a frequency domain correlation estimator for receiving said received signal transform and said reference signal transform and outputting an initial frequency offset estimate; and

7. a time domain correlation estimator for receiving said received signal transform and said reference signal transform and said initial frequency offset estimate and outputting a time offset estimate.

8. A method of synchronizing an orthogonal frequency division multiplexing (OFDM) receiver with a received OFDM signal comprising a multitone synchronization signal, comprising the steps of:

obtaining a coarse time offset estimate of said received signal;

sampling said received signal in a selected time interval to derive samples of said multitone synchronization signal;

analyzing said samples with respect to a reference multitone synchronization signal to obtain, for each sample analyzed, a time offset, a frequency offset, and a signal energy;

selecting a one of said analyzed samples with the greatest signal energy to yield a selected time offset estimate and a selected frequency offset estimate for use by said receiver in synchronizing with said received OFDM signal.

9. The method of claim 8, further comprising passing said selected time offset estimate and said selected frequency offset estimate to said receiver for use by said receiver in sychronizing with said received OFDM signal.

10. A method of carrying out OFDM communications comprising:

receiving an OFDM signal including within it a multitone synchronization signal;

locating said synchronization signal within said OFDM signal;

determining a time offset value of said synchronization signal;

determining an initial frequency offset value of said synchronization signal; and

recursively refining said frequency offset estimate to yield a selected pair of time and frequency offset values to be used by said OFDM receiver.

11. The method of claim 10, wherein said initial time offset value and said initial frequency offset value are determined by obtaining a correlation with a stored reference value of said synchronization signal.

12. The method of claim 11, wherein said correlation is performed seeking a maximum received synchronization signal energy level.

13. A method of carrying out OFDM communications comprising:

receiving, in an OFDM receiver, an OFDM signal including within it a multitone synchronization signal;

obtaining an FFT transform of said received signal;

obtaining an FFT transform of said reference multitone synchronization signal;

correlating said received signal transform and said reference signal transform and outputting an initial frequency offset estimate when said aforementioned transforms are maximally correlated; and

correlating said received signal transform and said reference signal transform and said initial frequency offset estimate and outputting a time offset estimate when said aforementioned transforms are maximally correlated.

14. An orthogonal frequency division multiplexing (OFDM) communication device, comprising:

means for receiving an OFDM signal containing a multitone synchronization signal;

means, coupled to said receiving means, for sampling a synchronization interval of said OFDM signal;

means, connected to said sampling means and said receiving means, for obtaining an initial time estimate and an initial frequency offset estimate of said OFDM signal;

means, connected to said receiving means, said sampling means and said estimating means, for obtaining a frequency offset estimate refinement; and

storage means, connected to said estimating means and said refinement means, for storing a reference multitone synchronization signal for use by said estimating means and said refinement means in calculating a time offset and a frequency offset of said multitone synchronization signal, said receiving means utilizing said time offset and said frequency offset to synchronize with said received OFDM signal.

15. The system of claim 14, wherein said estimating means further comprises:

a plurality of means for obtaining smoothed time-domain (TDC) correlation estimates, said smoothed TDC estimate means outputting a series of time offset estimate and correlation estimate pairs, each pair related to a frequency offset estimate; and

means for selecting a selected time offset estimate and a selected initial frequency offset based in part upon the selection of the frequency offset estimate and time offset estimate that corresponds with the largest value of correlation estimate.

16. The system of claim 15, wherein each of said smoothed TDC estimate means comprises:

a time domain correlator;

a smoothing filter connected to said time domain correlator and receiving an output from said time domain correlator; and

a maximum detector connected to and receiving an output from said smoothing filter for detecting a signal energy maxima representing a time estimate at which the energy of said reference multitone synchronization signal is at a maximum.

17. The system of claim 16, wherein the estimating means uses a coarse frequency discretization using F candidate frequency offsets.

18. The system of claim 15, wherein said reference multitone synchronization signal has a length of T, and wherein said refinement means comprises:

a T-length interval extractor for extracting a T-length sample of the output of said sampler;

a numerical oscillator for generating a complex exponential of a candidate frequency offset;

a multiplier for multiplying said T-length sample with said complex exponential to obtain a frequency shifted received signal;

a correlator for correlating said frequency shifted received signal with said reference multitone synchronization signal and producing a correlation output; and

a numerical optimizer for receiving said correlation output and outputting a new frequency offset candidate.

19. The system of claim 18, wherein said new frequency offset candidate and a time offset associated with said new frequency offset candidate are used by said receiving means if said new frequency offset candidate is a candidate that yields a maximum correlation output.

20. The system of claim 14, wherein said estimating means comprises:

first means for obtaining a first Fast Fourier Transform (FFT) of said received signal;

second means for obtaining a Fast Fourier Transform of said reference multitone synchronization signal;

frequency domain correlation estimate means for receiving said received signal transform and said reference signal transform and outputting an initial frequency offset estimate; and

time domain correlation estimator means for receiving said received signal transform and said reference signal transform and said initial frequency offset estimate and outputting a time offset estimate.

21. A device for synchronizing an orthogonal frequency division multiplexing (OFDM) receiver with a received OFDM signal comprising a multitone synchronization signal, comprising:

means for obtaining a coarse time offset estimate of said received signal;

means for sampling said received signal in a selected time interval to derive samples of said multitone synchronization signal;

means for analyzing said samples with respect to a reference multitone synchronization signal to obtain, for each sample analyzed, a time offset, a frequency offset, and a signal energy; and

means for selecting one of said analyzed samples with the greatest signal energy to yield a selected time offset estimate and a selected frequency offset estimate, wherein said selected time offset estimate and said selected frequency offset estimate are used by said receiver in synchronizing with said received OFDM signal.

22. The device of claim 21, further comprising means for passing said selected time offset estimate and said selected frequency offset estimate to said receiver for use by said receiver in synchronizing with said received OFDM signal.

23. A device for carrying out OFDM communications comprising:

means for receiving an OFDM signal including within it a multitone synchronization signal;

means for locating said synchronization signal within said OFDM signal;

means for determining a time offset value of said synchronization signal;

means for determining an initial frequency offset value of said synchronization signal; and

means for recursively refining said frequency offset estimate to yield a selected pair of time and frequency offset values to be used by said OFDM receiver.

24. The device of claim 23, wherein said initial time offset value and said initial frequency offset value are determined by obtaining a correlation with a stored reference value of said synchronization signal.

25. The device of claim 24, wherein said correlation is performed seeking a maximum received synchronization signal energy level.

26. A system for carrying out OFDM communications comprising:

means for receiving an OFDM signal including within it a multitone synchronization signal

means for obtaining an FFT transform of said received signal;

means for obtaining an FFT transform of said reference multitone synchronization signal;

means for correlating said received signal transform and said reference signal transform and outputting an initial frequency offset estimate when said aforementioned transforms are maximally correlated; and

means for correlating said received signal transform and said reference signal transform and said initial frequency offset estimate and supplying as an output a time offset estimate when said aforementioned transforms are maximally correlated.

27. An OFDM signal processor comprising:

an OFDM receiver for receiving an OFDM signal containing a multitone synchronization signal;

a synchronization interval sampler connected to said input and said receiver;

an initial time and frequency offset estimator connected to said sampler and said receiver; and

a frequency offset estimate refinement device connected to said receiver, said sampler and said estimator, wherein a reference multitone synchronization signal is used by said estimator and said refinement device in calculating a time offset and a frequency offset of said multitone synchronization signal, said receiver utilizing said time offset and said frequency offset to synchronize with said received OFDM signal.

28. The processor of claim 27, wherein said reference multitone synchronization signal is stored for retrieval in a memory connected to said estimator and said refinement device.

29. The processor of system of claim 27, wherein said initial time and frequency offset estimator comprises:

a plurality of smoothed time-domain correlation estimators for outputting a series of time offset estimate and correlation estimate pairs, each pair related to a frequency offset estimate; and

a selector for selecting a selected time offset estimate and a selected initial frequency offset based in part upon the selection of the frequency offset estimate and time offset estimate that corresponds with the largest value of correlation estimate.

30. The processor of claim 29, wherein each of said smoothed time domain correlation estimators comprises:

a time domain correlator;

a smoothing filter connected to said time domain correlator and receiving an output from said time domain correlator; and

a maximum detector connected to and receiving an output from said smoothing filter for detecting a signal energy maxima representing a time estimate at which the energy of said reference multitone synchronization signal is at a maximum.

31. The processor of claim 29, wherein the initial time and frequency offset estimator uses a coarse frequency discretization using F candidate frequency offsets.

32. The processor of claim 29, wherein said reference multitone synchronization signal has a length of T, and wherein said frequency offset estimate refinement device comprises:

a T-length interval extractor for extracting a T-length sample of the output of said sampler;

a numerical oscillator for generating a complex exponential of a candidate frequency offset;

a multiplier for multiplying said T-length sample with said complex exponential to obtain a frequency shifted received signal;

a correlator for correlating said frequency shifted received signal with said reference multitone synchronization signal and producing a correlation output; and

a numerical optimizer for receiving said correlation output and outputting a new frequency offset candidate.

33. The processor of claim 32, wherein said new frequency offset candidate and a time offset associated with said new frequency offset candidate are used by said receiver if said new frequency offset candidate is a candidate that yields a maximum correlation output.

34. The processor of claim 32, wherein said initial time and frequency offset estimator comprises:

a first Fast Fourier Transformer for obtaining a transform of said received signal;

an second Fast Fourier Transformer device for obtaining a transform of said reference multitone synchronization signal;

a frequency domain correlation estimator for receiving said received signal transform and said reference signal transform and outputting an initial frequency offset estimate; and

a time domain correlation estimator for receiving said received signal transform and said reference signal transform and said initial frequency offset estimate and outputting a time offset estimate.

35. An OFDM transmitter comprising:

means for transmitting an OFDM signal comprising a first time interval and a second time interval;

means for transmitting data at one or more data frequencies during said first time interval; and

means for transmitting, during said second time interval, a synchronization tone, at one or more synchronization frequencies, for a predetermined time period, the frequencies of said synchronization tone being distinct from said data frequencies.

36. A method for transmitting an OFDM signal comprising the steps of:

transmitting an OFDM signal comprising a first time interval and a second time interval;

means for transmitting data at one or more data frequencies during said first time interval; and

means for transmitting, during said second time interval, a synchronization tone, at one or more synchronization frequencies, for a predetermined time period, the frequencies of said synchronization tone being distinct from said data frequencies.